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Review Article

Linking agroecosystems producing farmed seafood with food security and health status to better address the nutritional challenges in Bangladesh

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Abstract
Objective: Aquaculture is one of the fastest-growing food production sectors in many low-income and food-deficit countries with aquatic ecozones. Yet its specific impact on nutrition and livelihood in local communities, where commercial and/or export-orientated aquaculture activities are developed, is largely unknown.
Design: The present narrative and argumentative review aims to provide an overview of our current understanding of the connections between aquaculture agroecosystems, local and national fish production, fish consumption patterns and nutrition and health outcomes.
Results: The agroecological dynamic in a coastal-estuarine zone, where the aquatic environment ranges from fully saline to freshwater, is complex, with seasonal and annual fluctuations in freshwater supply creating a variable salinity gradient which impacts on aquatic food production and on food production more generally. The local communities living in these dynamic aquatic ecozones are vulnerable to poverty, poor diet and health, while these ecosystems produce highly valuable and nutritious aquatic foods. Policies addressing the specific challenges of risk management of these communities are limited by the sectoral separation of aquatic food production – the fisheries and aquaculture sector, the broader food sector – and public health institutions.
Conclusions: Here we provide an argument for the integration of these factors to improve aquaculture value chains to better address the nutritional challenges in Bangladesh.

Keywords
Agrosystems
Aquaculture
Low-income and food-deficit countries
Food security
Nutritional status
Bangladesh

Aquaculture represents a fast-growing food production sector in many low-income and food-deficit countries (LIFDC). In certain South-East and South Asian countries, like Bangladesh and Vietnam, the contribution of aquaculture to gross domestic product is now over 2·5 %, indicating that aquaculture is an important contributor to the countries' economy performance[1,2]. In the ten leading aquaculture countries in the Global South, farmed fish is increasingly available and accessible to poor urban and rural consumers in these markets[3]. Yet the specific impacts of commercial aquaculture on food security, nutritional status and livelihood in local communities where it is located are poorly understood. On a global scale, the importance of aquaculture in enhancing the resilience of the world food supply has been questioned[4], and aquatic products have often remained neglected in food security analyses, despite their important role in world trade, human nutrition and support for livelihoods[1]. Indeed, while its role in securing

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livelihoods of poor households through employment in fishery and aquaculture supply and value chains is well established[5,6], aquaculture's contribution to food security, as well as to nutritional status as a consequence of increased fish consumption, has been largely ignored in international debate. A recent review found that fish consumption was absent from strategies for reduction of micronutrient deficiency[7]. The disconnect between nutrition and seafood continues; the recent Global Nutrition Report makes no mention of the role of seafood in human diets because the Sustainable Development Goal most linked to aquaculture (SDG14, Life under the water) has no 'nutritionally relevant' indicators[8]. The real importance of fish consumption occurs in LIFDC; in 2010, of the thirty countries where fish contributed more than one-third of the total animal protein intake, twenty-two were LIFDC[9].

The evidence that emergent commercial aquaculture in LIFDC has had important effects on local livelihoods and the environment has not been matched with detailed studies of its direct impacts on peoples' nutritional status, health and well-being[10]. A review of the literature on the relationship between aquaculture and poverty, food security, food production sustainability and gender equality found that, although there were a number of studies identifying income benefits, these analyses were less relevant for consumption in poor households[11]. Recently, the impacts of deteriorating marine fish catches on human health was modelled using the declines in intakes of critical nutrients as indicators[12]. However, this global model was limited to marine fisheries and cannot make predictions for highly complex agroecological food systems characterizing many LIFDC. The present study reviews our current understanding of connections between aquaculture agroecosystems, fish production and consumption patterns in relation to nutrition and health outcomes, discussing how integration of such factors may improve impact on food security, nutritional status and well-being in Bangladesh.

Methods

Here we present a narrative review discussing evidence from interdisciplinary research fields including agroecosystems producing farmed seafood, food security and nutritional status. The review was conducted by an interdisciplinary group of authors. It contains argumentative elements to explore how integration of such interdisciplinary factors could improve future impact on food security, nutritional status and well-being in Bangladesh.

Aquaculture production systems in Bangladesh

The ecosystems

The geographical characterization of South-East and South Asian countries is diverse, and aquaculture systems vary according to position – coastal or inland – and salinity gradient.

In Bangladesh, the agroecological dynamics of aquaculture are complex in a coastal zone ranging from saline to freshwater aquatic environments, with seasonal and annual fluctuations in freshwater availability. The variable salinity gradients impact on aquaculture specifically and on food production more generally[13]. Local adaptation and risk management in terms of strategic cropping of rice and vegetables *v.* production of shrimp and finfish are common as people respond to changes to water regimes. For example, export-orientated shrimp aquaculture, that has developed to dominate land use in estuarine flood plains of many coastal LIFDC, causes a range of impacts on local livelihoods. Pressures from a growing human population and the quest for economic benefit are now transforming marginal agroecosystems in LIFDC, including coastal wetlands that are vulnerable to climate change and salinization[13]. The livelihoods of the rural poor are increasingly dependent on alternative land-use strategies and aquaculture has often become a key component of food production[6], mostly alongside continued exploitation of unstocked aquatic animals[14]. The impacts of such changes are not limited to the producers, or even producer communities themselves, as the poor are often intrinsic members of associated value chains and/or consumers throughout a much broader geography[15]. Key drivers to this dynamic are both the declining harvests of wild aquatic stocks and the growth in demand driven by increasing, often urban, populations consuming more nutritious diets[16,17].

Aquaculture in food systems

After three decades of sustained growth, aquaculture now accounts for 53 % of reported fish production[18], although pathways to consumption are less well understood. Farmed seafood now contributes nearly 50 % of total direct human consumption globally, but in some countries such as Bangladesh, its rise has been comparatively more important[19], given the context of fish being the most accessible and also preferred choice of animal-source foods. On the global level, significant diversity in consumption levels of seafood (total and as a percentage of animal-source protein) and spatial importance of aquaculture production (as the contribution to gross domestic product) suggest some important mismatches. Indeed, although high consumption levels are met by high production in in South-East and South Asia, demand for fish as a source of animal protein in West and Central Africa cannot be met by current levels of indigenous aquaculture, despite years of sector growth[1]. Moreover, on the local level, access of vulnerable individuals to farmed seafood within the community or even within the household is influenced by a range of social and individual factors.

Role of aquaculture in the sustainable development of Bangladesh

The challenge to meeting the sustainability agenda of the UN in Bangladesh is immense and linked to its poverty and estuarine environment[20]. The positive economic growth of Bangladesh in recent years has been based largely on the rise of 'non-traditional exports', garments and the mainly farmed shrimp and prawn[21]. Aquaculture, mainly practised in southern coastal areas, has grown to constitute about 60 % of primary product exports, but has given rise to considerable criticism on environmental and social grounds[22]. The well-publicized negative consequences of shrimp culture[22] include impacts related to general salinization of the environment, which can reduce terrestrial diversity and possibly impoverish local diets and negatively impact on community social welfare. On the other hand, however, it has also been found that aquatic diversity can be enhanced in such environments, and a wide range of naturally recruited 'co-products' of indigenous fish are harvested from the commercial ponds, destined for local consumption[13]. This appears to be particularly the case in extensive and semi-intensive production systems characteristic of Bangladesh. We recently showed that small homestead ponds, raising both fish and vegetables, can contribute to a wider food supply, reduced poverty and enhanced food security, which would be especially critical for food-vulnerable rural households compared with peri-urban households, and which would be most important during the lower income months[23]. But the role of aquaculture located in different agroecosystems also needs to be assessed. Recent research found that the hydrological forces in south-west Bangladesh are actively displacing a zone of transition between fresh and brackish water southwards despite a countervailing trend of rising sea level. Thus, the agro- and aquaculture systems in such highly dynamic environments are continually being adapted to both environmental and market factors[13].

Role of aquaculture in economic development and poverty reduction

Previous attempts to explore the associations between commercial aquaculture and poverty as a measure of its impact on economic development have focused mainly on the direct and indirect contribution to poverty reduction for the poor entering into paid employment[24]. A study in the Philippines used Gini decomposition of income due to employment generation and showed that commercial shrimp culture reduced economic inequality in several coastal villages[25]. The contribution of aquaculture to poverty reduction has been related to both the direct and indirect contributions of increased income and consumption in Bangladesh[10,15]. There is a lack of empirical studies that show the impact of indirect consumption through increased availability of fish in the markets and increased accessibility of fish due to reduced price. Household income and expenditure survey data can be used to demonstrate if aquaculture is 'pro-poor', where pro-poor aquaculture growth is defined as the 'quantity of fish eaten by poor consumers increases by a greater amount than the quantity of fish eaten by non-poor consumers'[10]. Better information on the specific nutritional, health and well-being outcomes that are related to changes in the 'food-scape' around aquaculture production, especially for the most vulnerable groups such as adolescent females, is required to inform future policy support for further transformation of rural landscapes and the livelihoods they support.

Fish consumption and health outcomes in Bangladesh

Fish consumption in Bangladesh

Fish consumption across Bangladesh is not well documented. The most recent and representative data evaluate fish consumption patterns based on 24 h recall data collected as part of the Bangladesh Integrated Household Survey (BIHS) between October 2011 and March 2012[26]. The average intake of fish (fresh fish and dried fish converted to fresh weight) was 67 and 75 g per person per day for adult women and men, respectively, across all wealth groups. Fish consumption among the poorest quintile wealth group was about half this amount, 35 *v.* 78 g per person per day for adult women. Less than half of children under the age of 2 years had been fed animal-source foods the previous day, and the portion sizes were very small, despite the mothers' awareness of the importance of feeding their children fish or other animal-source foods[26]. However, the period covered in the study included the peak season for fish supply in Bangladesh and therefore average fish consumption figures across the year may be lower.

In food system analysis, it is important that the relationship between fish intake and fish supply can be evaluated. Food balance sheets from the FAO's statistical database (FAOSTAT), providing data on quantities of food available to consumers based on production and trade between 2009 and 2011[27], have shown the unique importance of fish availability in the food system in Bangladesh among five fish-producing Asian LIFDC, including China and India (Fig. 1). While the total available food supply in terms of dietary energy per capita is relatively comparable between the five countries (Fig. 1(a)), in Bangladesh the supply of animal-based foods (meat, egg, milk and seafood) contributes significantly less to total available dietary energy (Fig. 1(b) and (d)), fat (Fig. 1(e)) and protein (Fig. 1(f)) compared with availability in the other countries. On the contrary, the contribution of animal-based foods from fish and seafood (Fig. 1(c) and (g)–(i)), and particularly freshwater fish (Fig. 1(j)–(l)), to dietary energy, fat and protein intakes is among the highest across the countries investigated. The food system in Bangladesh is characterized by a generally sufficient – not alarming – per capita total supply of dietary energy and protein, but very low supply of fat and a very low total supply of animal-source foods[27].

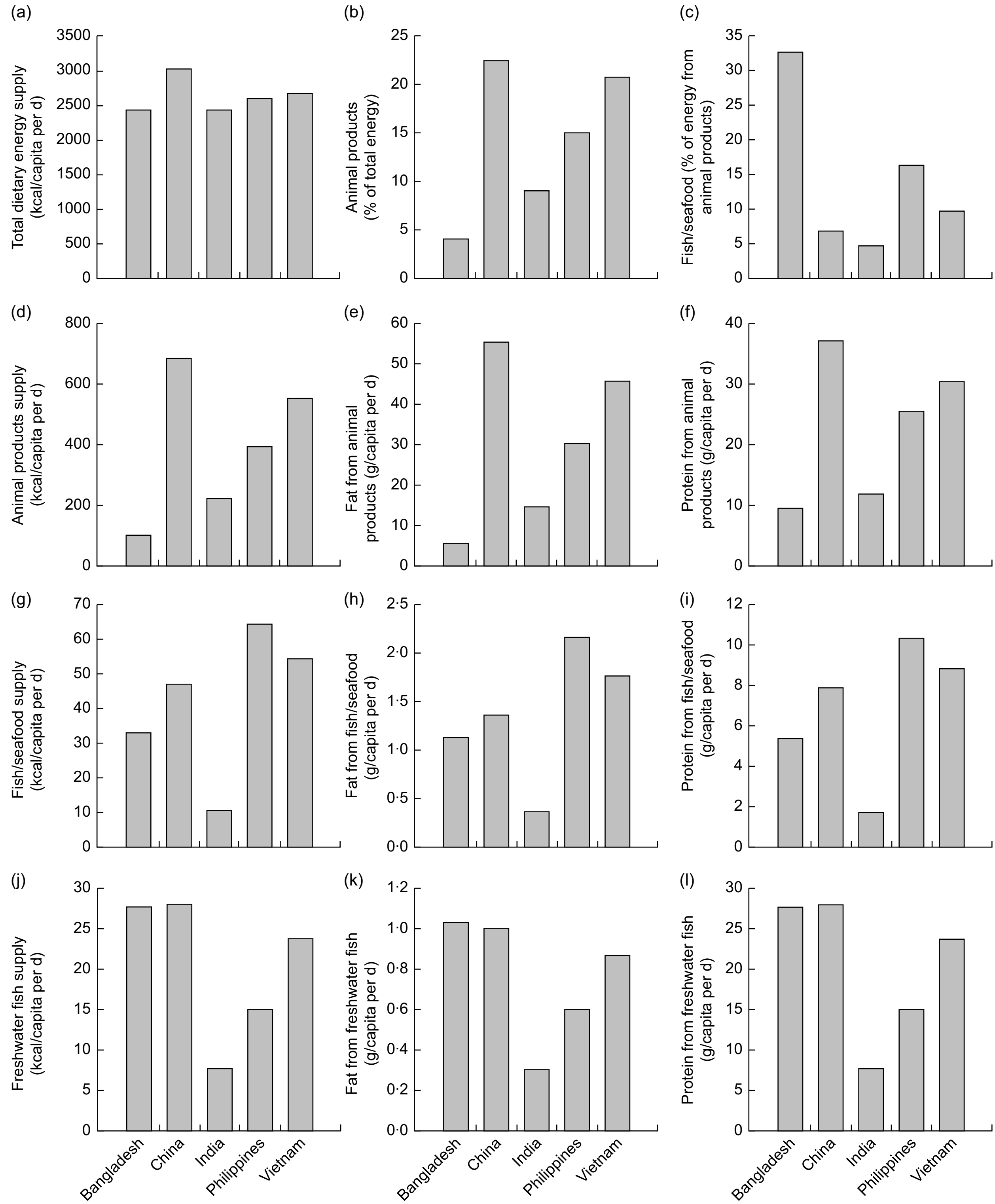

Fig. 1 Quantities of foods and nutrients available to consumers in five fish-producing, low-income and food-deficit countries in Asia based on production and trade. Data obtained from food balance sheets from the FAO's statistical database (FAOSTAT) 2009–2011[27]. (a), (b), (d), (e) and (f) availability of animal-based food and nutrients; (c), (g), (h) and (i) availability of animal-based food and nutrients from fish and seafood; (j), (k) and (l) availability of animal-based food and nutrients from freshwater fish. To convert to kJ, multiply kcal values by 4·184

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However, despite the very low availability of fat, a previous study also deriving data from FAOSTAT showed that Bangladesh did appear to have a relatively good supply of total n-3 PUFA compared with other LIFDC[28]. In this context, the contribution from fish and seafood is significant and therefore any changes to the supply and accessibility of aquatic foods will impact on the dietary quality of the population.

Fish consumption and health outcomes

Consumption of seafood may be able to alleviate the often multiple micronutrient deficiencies that are highly prevalent in the Bangladeshi population[20]. In this country, fish is the most important nutrient-rich food in the diet across population groups and ages, being a valuable contributor to the reference nutrient intakes for a range of micronutrients, in addition to being an important source of protein and energy[29]. Indeed, promotion of the consumption of mola carplet, a small indigenous fish high in vitamin A, appears a cost-effective approach to increase vitamin A intake, reduce the prevalence of inadequate vitamin A intake and generally reduce the burden of micronutrient malnutrition in Bangladesh[30]. Furthermore, dietary long-chain n-3 PUFA from fish have well-documented positive impacts on the brain development of infants and children[31]. In relation to this, it has been observed that the weight and head circumference of babies at birth have been positively associated with seafood consumption in Norwegian mothers[32].

Between 1991 and 2010, fish consumption increased by 30 %, and, with fish being the major protein source of a typical Bangladeshi diet consisting of polished rice, fish and vegetables, this has also led to significant increases in average energy, protein and fat intakes from fish, both nationally and for all poverty groups[29]. However, while protein levels vary little, micronutrient levels do vary across fish species[33] and, more generally, the nutritional quality of farmed species is known to be decreased for some species due to global changes in fish feed composition[34–36]. This may have contributed, for example, to a significant decrease in Fe and Ca intakes from fish in the general Bangladeshi population, despite an increase in fish consumption in the past 20 years[29]. The impact of seafood consumption in populations in LIFDC is, however, blurred by the multiple health impacts of poor living conditions, such as a high infectious disease burden and generally poor nutritional quality of diets. While there exists a positive correlation between fish and seafood supply and male height (with low height being an indicator of stunted growth in early life) in Europe, this correlation is negative for fish and seafood supply, especially freshwater fish supply, and male height in populations in Asia and Africa[37]. This may indicate a higher dependency on fish, particularly freshwater fish, in LIFDC populations compared with high-income countries.

It was recently reported that obesity, hyperglycaemia and raised blood pressure are important but unrecognized health threats in rural Bangladesh, indicating a need for new treatment strategies to preventing the growing burden of non-communicable diseases like diabetes and CVD[38]. Indeed, low-income and middle-income countries like Bangladesh suffer the largest burden of morbidity and mortality due to non-communicable diseases[39]. Therefore, the inverse relationship between fish consumption and risk for CHD and stroke, as established in two recent meta-analyses in mostly Western populations[40,41], may become increasingly relevant for the treatment and prevention of non-communicable diseases in LIFDC such as Bangladesh.

Linking aquaculture agroecosystems with nutritional health outcomes to address the nutritional challenges in Bangladesh

Current nutritional and health challenges in Bangladesh

Bangladesh has one of the worst rates of malnutrition in the world: 36 % of children under the age of 5 years are stunted, 33 % of children under 5 years are underweight and millions of people have micronutrient deficiencies[42]. Deficiencies in folate, Zn, vitamins A, B_6, B_{12}, C, E and riboflavin, mainly resulting from inadequate dietary intake of animal-source foods, fruits and vegetables, are highly prevalent and may occur concurrently among pregnant women[43], albeit that the prevalence of Fe deficiency is low, contrary to the widely held assumption, possibly as a result of high levels of Fe in groundwater[44]. Multiple nutrient deficiencies are generally observed in populations with low socio-economic status[45]. However, despite many challenges, Bangladesh has made improvements in the health outcomes of its children. Stunting in children under 5 years has declined by nearly 1·4 % per year between 1997 and 2011, with the key drivers for this change being multidimensional: improvements in parental education, household assets, sanitation and heath-care use, for example[46]. The WHO currently recommends Fe and folic acid supplementation for pregnant women to prevent maternal anaemia, puerperal sepsis, low birth weight and preterm birth, and this is also implemented in Bangladesh. However, Fe–folic acid supplementation often starts too late in the pregnancy to have impact on maternal nutrition and birth outcome. This supports the case for public health interventions to include nutritional interventions in addition to supplementation regimens to improve nutritional status and thereby maternal and child health outcomes. Indeed, it has been argued, for example, that Zn biofortification of rice has the potential to markedly improve Zn adequacy in diets in rural Bangladeshi populations[47]. Moreover, a recent systematic review concluded that dietary interventions and fortified food products were effective in increasing birth weight and reducing the incidence of low birth weight[48].

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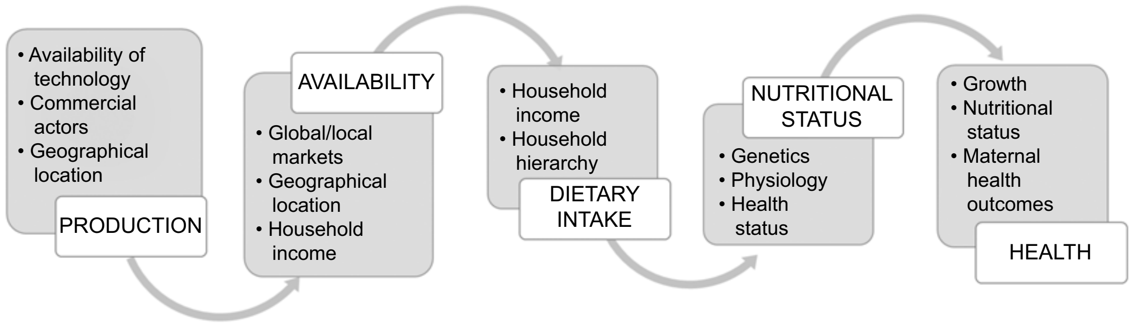

Fig. 2 Schematic interpretation of links between aquaculture production systems, food availability, dietary intakes, nutritional status and individual health

Increasingly we acknowledge that improvements in nutritional and health status on the individual, local and national level depend on a complex network of interacting factors that drive food production, food availability and dietary intake, and by linking these we may be able to better address the nutritional challenges in Bangladesh (Fig. 2). Currently, policies addressing the specific challenges of risk management of these communities are characterized by the sectoral separation of aquatic food production – the fisheries and aquaculture sector and the broader food sector – and public health institutions. Indeed, a succession of national policies have acknowledged the importance of food security at the national, household and individual level in the agro-based economy of Bangladesh, stressing the importance of increasing production and processing in the fisheries sub-sectors in an environment-friendly and sustainable manner, without addressing the impact on human diet and health outcomes[49–51]. Likewise, several national policies have set out strategies to improve the overall health, nutritional status, survival, growth, development and productivity of the population by preventing and alleviating micronutrient deficiencies, as well as ensuring quality and equitable health care for all citizens of Bangladesh by gradually achieving universal health coverage, without addressing the impact of food production and distribution[52,53]. It is therefore difficult to assess how government policies on fish production impact on nutritional status and human health, and vice versa, in Bangladesh.

Cultural factors affecting dietary intake, nutritional status and health in Bangladesh

One main problem with linking factors like dietary intake, nutritional status and health (Fig. 2) is that for the measurement of dietary intake, data are commonly collected at the household level. However, in Bangladesh, differential access to food within households, with a tendency of disfavouring females, is a cultural norm[54]. This means that dietary intake data may not necessarily align with nutritional status and health outcomes, especially in adolescent girls and young women. Adolescent girls represent a vulnerable group in Bangladesh. They have lower access to food but at the same time have higher nutritional requirements: for their own growth, as well as – in the case of early marriage and motherhood – for the *in utero* growth of the fetus and for breast-feeding the infant (the critical '1000 days')[55]. Indeed, in Bangladesh, almost 30 % of adolescent girls are married before 14 years of age, with almost 60 % married by the age of 16 years; the country has been ranked third in the prevalence of child marriage globally[56]. Greater female autonomy, which has been found to confer improved food and resource allocation within the family, has been strongly linked to female employment, especially outside the home[57]. Given the large increase in female employment related to export-led processing of farmed seafood, a value chain approach, in which employment within entities involved in the forward and backward trade linkages with production is assessed, is critical to understanding the interactions of nutrition and health outcomes.

Aquaculture production factors affecting nutritional and health status

It is currently unclear how exactly aquaculture production systems contribute to population and individual health, and how this relationship may be affected by food availability, dietary intakes and nutritional status on the local level (Fig. 2). Global value chain frameworks containing information on product, process, functional and interchain categories[58–60] acknowledge the growing link between intensifying aquaculture in LIFDC and global markets[8]. However, typically, such frameworks do not include value add-ons such as food security, nutritional status, health and well-being outcomes. Despite the apparent lack of systematic approaches and methodologies to assess impact on health and related quality of life[61], these are necessary to create a better understanding of impacts of access to aquatic foods on health and nutrition – resulting in the development of more integrated policy models to evaluate the effectiveness and cost-effectiveness of interventions on lifetime health outcomes[62], as well as informing policy decisions for practice in the development of farmed aquatic systems. Analysis of global patterns in seafood reliance, malnutrition level and economic prospects has already indicated that island nations in South-East Asia have the best opportunities for the farming of marine species[63]. However, frameworks and metrics for the linkages between terrestrial agroecosystems and nutritional and health outcomes, including in Bangladesh, highlight the need for more research on in-country specific settings including dietary diversity and the role of women in food production and distribution[64]. Furthermore, the very specific complexity of the dynamic coastal ecosystems with fluctuating salinity, and the dependency of local communities on aquatic food resources, remain to be conceptualized for the aquaculture/fisheries and health sector. Monitoring of the consequences of natural and man-made developments in these extremely dynamic agroecological systems will be necessary to provide information on the nutritional, health and well-being outcomes of local residents that are related to the value chain and changes in the 'foodscape' relating to aquaculture production.

Conclusion

Establishing the relationships between aquaculture agro-ecosystems producing nutritious foods, and their impact on the health and nutritional status of local communities living in such dynamic aquatic ecozones, is currently challenging for various reasons. These include the complex ecological dynamics of seasonal and annual fluctuations in freshwater supply and variable salinity gradients in aquatic environments, which is especially relevant for a country like Bangladesh. It also includes difficulties with the accurate assessment of fish consumption and how this relates to individual health outcomes, as this relationship can be confounded by many factors, including the health impacts of poor living conditions, such as the high prevalence of infectious diseases and generally poor nutritional quality of diets. Access to and availability of fish is another factor to consider, including geographical locations, access to global and local markets, and household income. Populations in LIFDC are more dependent on fish, particularly freshwater fish, to ensure sufficient intakes of energy, protein and fat, and fish consumption may affect also growth and micronutrient status. Therefore, it is important that global value chain frameworks, which are currently mostly focusing on product, process, functional and interchain categories, include factors such as food security, nutritional status, health and well-being outcomes in the future. This will provide a better understanding of impacts of access to aquatic foods on health, resulting in a more integrated and relevant policies and practices when further developing farmed aquatic systems.

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